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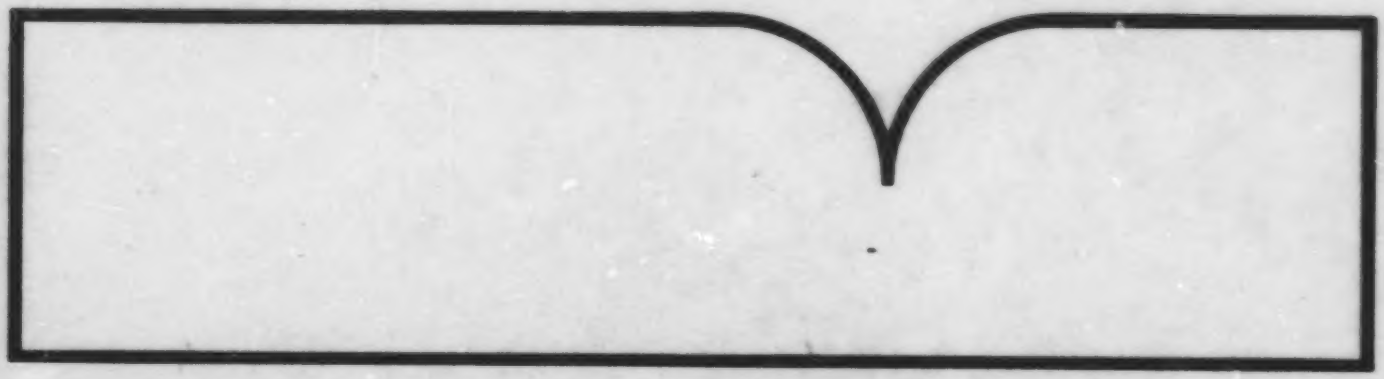
Summary of the Western Energy Overhead Monitoring Project

Lockheed Engineering and Management Services Co., Inc., Las Vegas, NV

Prepared for

Environmental Monitoring and Support Lab.
Las Vegas, NV

Nov 80



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15. SUPPLEMENTARY NOTES
G. A. Shelton, Project Officer, Advanced Monitoring Systems Division, Environmental Monitoring Systems Laboratory, Las Vegas, Nevada 89114

16. ABSTRACT

The Environmental Protection Agency and the National Aeronautics and Space Administration entered into a five-year overhead monitoring project in June, 1975. The purpose of this joint project was to transfer, from NASA to EPA, hardware and software technology for processing remotely sensed digital data and to assist EPA in developing and maintaining an operational remote sensing monitoring system. The overall objective was to define, develop, and demonstrate operational remote sensing techniques to rapidly monitor, in a cost-effective manner, the success with which an energy-related extraction site has been, or is being, rehabilitated. This report discusses the technology transfer that has successfully taken place. It also describes the remote sensing monitoring system EPA has established and concludes that this system can be used to effectively monitor surface mining reclamation activities on a case-by-case basis but is less suitable for production-type monitoring requiring the quick turnaround processing of data for hundreds of energy-related extraction sites.

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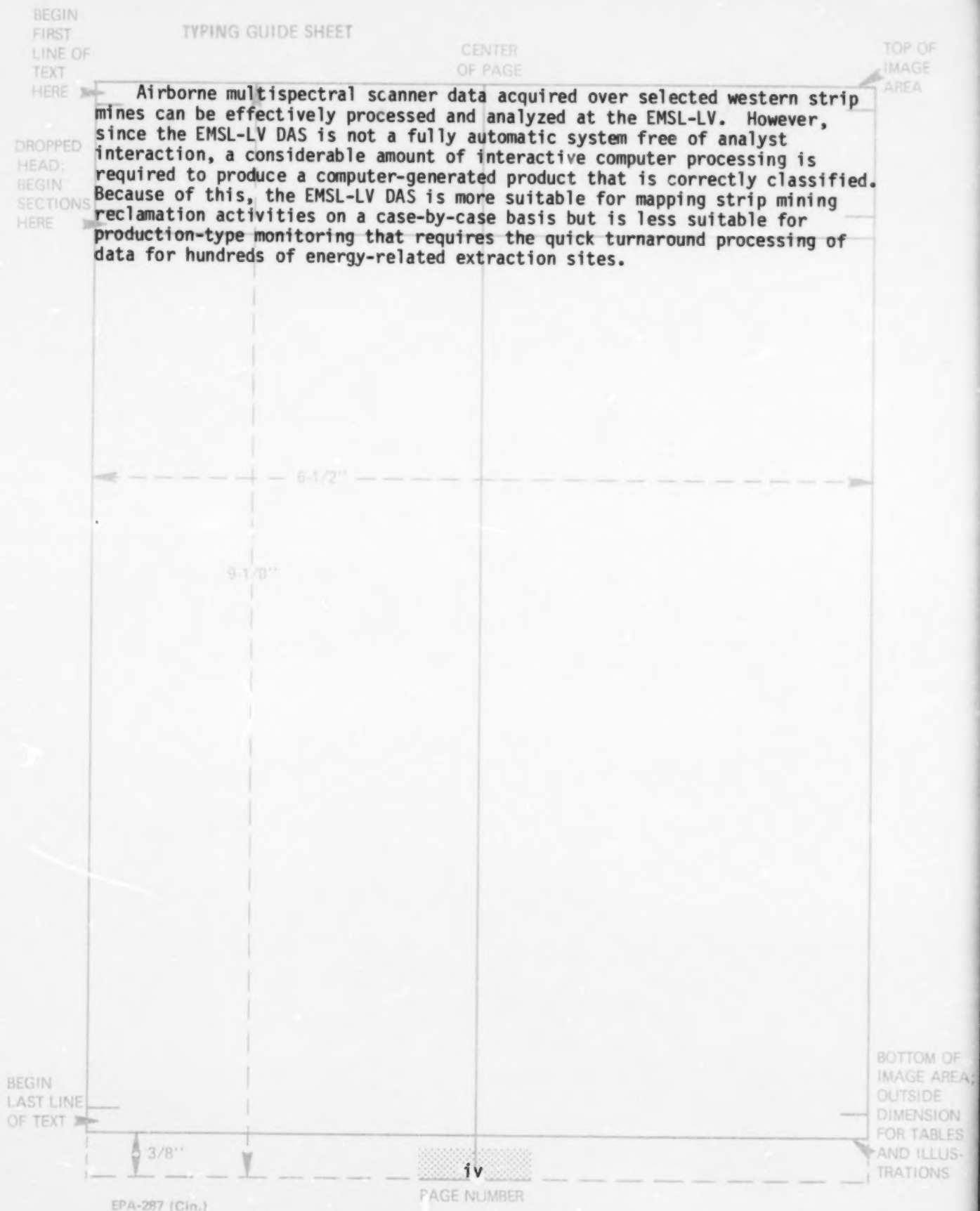
SUMMARY

In June of 1975 the Environmental Protection Agency (EPA) and the National Aeronautics and Space Administration (NASA) entered into a five-year, EPA-funded project which later was to be called the Western Energy Overhead Monitoring Project. The purpose of this joint undertaking was to transfer hardware and software techniques for processing remotely sensed digital data from NASA to EPA in order that EPA could develop the capability of establishing and maintaining a fully operational remote sensing monitoring system. Such an operational system was perceived to be a valuable tool for monitoring surface reclamation activities at coal strip mines in the western United States. This being a major consideration, the overall objective of the project was to define and develop operational remote sensing techniques and demonstrate that these techniques could be used in monitoring, in a rapid and cost-effective manner, the success with which an energy-related extraction site has been, or is being, rehabilitated.

The project was divided into three phases. The main emphasis in Phase I was the transfer of a Data Analysis System (DAS) and its software technology and maintenance requirements to the Environmental Monitoring Systems Laboratory in Las Vegas, Nevada (EMSL-LV). In Phase II, EMSL-LV used the system on a shakedown basis while the NASA National Space Technology Laboratory (NSTL) in Slidell, Louisiana, used a similar system to investigate and research specific problems defined by EMSL-LV. In Phase III, EMSL-LV used and tested the system in an operational mode and upgrades in hardware and software were made.

The bulk of the technology transfer was successfully accomplished during Phase I but periodic upgrades continued into Phase III. Throughout the project valuable experience was acquired in developing and maintaining an operational remote sensing monitoring system, in obtaining remotely sensed digital data, and in processing the digital data on the EMSL-LV DAS.

The acquisition and processing of the scanner data during the Western Energy Project demonstrates that the EPA remote sensing monitoring system can be used to successfully detect and map, in a cost-effective manner, land use/land cover features associated with strip mining activities in the western United States. It is a versatile system with various processing options available. With the system, it is possible to geographically correct scanner data so that classified scanner images can be directly correlated to topographic maps for easy mapping of land use category distributions. In addition, accurate area and percentage figures can be obtained for each classified land use category.



Airborne multispectral scanner data acquired over selected western strip mines can be effectively processed and analyzed at the EMSL-LV. However, since the EMSL-LV DAS is not a fully automatic system free of analyst interaction, a considerable amount of interactive computer processing is required to produce a computer-generated product that is correctly classified. Because of this, the EMSL-LV DAS is more suitable for mapping strip mining reclamation activities on a case-by-case basis but is less suitable for production-type monitoring that requires the quick turnaround processing of data for hundreds of energy-related extraction sites.

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Sincere thanks are extended to Mr. Charles E. Tanner, formerly of Lockheed Engineering and Management Services Company, Incorporated, for documenting Phases I, II, and III of the Western Energy Overhead Monitoring Project and for assisting in the preparation of this summary report.

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SECTION 1

INTRODUCTION

Since its establishment in 1970, the U.S. Environmental Protection Agency (EPA) has been involved in energy-related environmental research, including the development of pollution control technology, as necessary to meet its statutory responsibilities. EPA's primary mission is environmental protection, and its objective in the energy area is to enable energy development to progress as rapidly as possible while assuring that national environmental goals are met.

As the nation strives to reduce its dependence on foreign energy, increased attention must be given to the environmental problems arising from domestic energy resource development. On the federal level, this need has been recognized by the expansion of energy-related environmental research and development programs undertaken by a number of federal departments and agencies.

Centralized coordination of a number of these expanded efforts is provided via the Federal Interagency Energy/Environmental Research and Development Program formerly administered by the Environmental Protection Agency's Office of Energy, Minerals, and Industry (OEMI). The primary purpose of the interagency program is to assure that our national energy goals are matched with an effective research and development program in the critical areas where energy needs and environmental protection goals overlap.

With this in mind the Environmental Protection Agency and the National Aeronautics and Space Administration (NASA) entered into a 5-year, EPA-funded project in June of 1975. The purpose of this interagency project was twofold: to transfer hardware and software techniques for processing remotely sensed digital data from NASA to EPA and to assist EPA in developing the capability of establishing and maintaining a fully operational remote sensing monitoring system.

Laboratories through which the 5-year plan would be implemented were designated by both agencies. The NASA National Space Technology Laboratory (NSTL, formerly the Earth Resources Laboratory) located in Slidell, Louisiana, and the EPA Environmental Monitoring Systems Laboratory in Las Vegas, Nevada, (EMSL-LV) were the two agency laboratories involved.

The overall objective of this 5-year project was to define, develop, and demonstrate operational remote sensing techniques to rapidly monitor, in a

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cost-effective manner, the success with which an energy-related extraction site has been, or is being, rehabilitated to a state suitable for its intended or previous land usage.

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The two participating agencies agreed to divide the 5-year project into three distinct phases based on operational requirements. Phase I was begun in July of 1975 and continued for 18 months. During this time technology transfer of software and hardware capabilities, and data reduction of aircraft-acquired and Landsat multispectral scanner data were performed and evaluated.

Phase II of the project was begun in January of 1977 and was 18 months in duration. During this phase, EMSL-LV used the system on a shakedown basis for monitoring purposes. Also, during this time, NSTL used a similar system to investigate and research specific problems defined by EMSL-LV.

During Phase III, EMSL-LV used and tested the system in an operational mode. In addition, software and hardware upgrades were made and the system was refined to make processing faster and more economical.

This report summarizes the events that occurred in the various phases of the Western Energy Overhead Monitoring Project. Technical details of the data acquisition, data processing, and analytical procedures will not be addressed in this report. These details have been discussed in previous reports documenting each phase of the Western Energy Overhead Monitoring Project. These earlier reports are listed in the annotated bibliography.

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SECTION 2

CONCLUSIONS

The Western Energy Overhead Monitoring Project demonstrates that airborne multispectral scanner data and computer processing techniques can be used to detect and map land use/land cover features associated with coal strip mining activities in the western United States. Through the joint efforts of NSTL and EMSL-LV, a Data Analysis System for Monitoring strip mining activities has been established at EMSL-LV.

As a result, airborne multispectral scanner data acquired over selected western strip mines can be effectively processed and analyzed at EMSL-LV. However, since the EMSL-LV DAS is not a fully automatic system free of analyst interaction, a considerable amount of interactive computer processing is required to produce a computer generated product that is correctly classified. Because of this the EMSL-LV DAS is more suitable for mapping strip mining reclamation activities on a case-by-case basis rather than monitoring a large number of coal strip mines on a production basis.

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SECTION 3

RECOMMENDATIONS

Based on the results and conclusions from the three phases of the Western Energy Overhead Monitoring Project, the following recommendations are proposed for consideration:

- For optimum processing, obtain scanner data at altitudes that will enable the scanner to resolve features of interest and at sun angles that will minimize shadow interference; eliminate excessive computer processing by obtaining scanner data at scales that will allow the entire target area to be displayed on a single computer scene; and edit excessive data.

- Augment the use of automatic data processing with photographic interpretation as the means for developing baseline information. Computer classification techniques can be relied upon to quickly and correctly classify scanner data containing features having unique spectral characteristics, but in situations where features of interest cannot be resolved spectrally, resulting in the misclassification of data, photographic interpretation proves to be more productive.

- Investigate the feasibility of digitizing photo-interpreted aerial photography for use as baseline information if production work is proposed.

- Investigate the use of the EPA data base as a means to store and update changes that occur at strip mining sites.

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SECTION 4

PHASE I

Phase I of the Western Energy Overhead Monitoring Project began in July of 1975 and was 18 months in duration. The overall objective of this phase was to develop and demonstrate the techniques and procedures for deriving vegetation/land cover classifications of coal strip mine sites and their environment for the purpose of subsequent monitoring of the rehabilitation efforts on mined areas. The specific objectives were to:

- Transfer the Data Analysis System and its associated software technology and maintenance requirements to EMSL-LV.
- Perform automated analysis of aircraft MSS data and manual classification of photographic data over selected coal strip mine sites.
- Determine the utility of Landsat MSS data for performing a regional land cover classification of a portion of the Powder River Basin.
- Compare the results obtained from the aircraft MSS classification with the manually photointerpreted results.

The Western Energy Project was appropriately named because the study area was composed of seven states located west of the Mississippi River. These states, moving westwardly, were North Dakota, Montana, Wyoming, Colorado, New Mexico, Arizona, and Utah. All states had active surface mining operations in many areas. Because of aircraft flight limitations and other criteria, eight mines were selected from five of the seven states for the study.

DATA ACQUISITION

Data acquisition occurred during the months when the chlorophyll content of vegetation was at its maximum at the selected coal strip mine sites (Figure 1).

Flight lines were drawn on partial or full-frame color infrared film enlargements (1.02 meter format) and also black-and-white full-frame enlargements produced by EMSL-LV personnel from NASA high-altitude aerial photography acquired prior to the low-altitude data collection.

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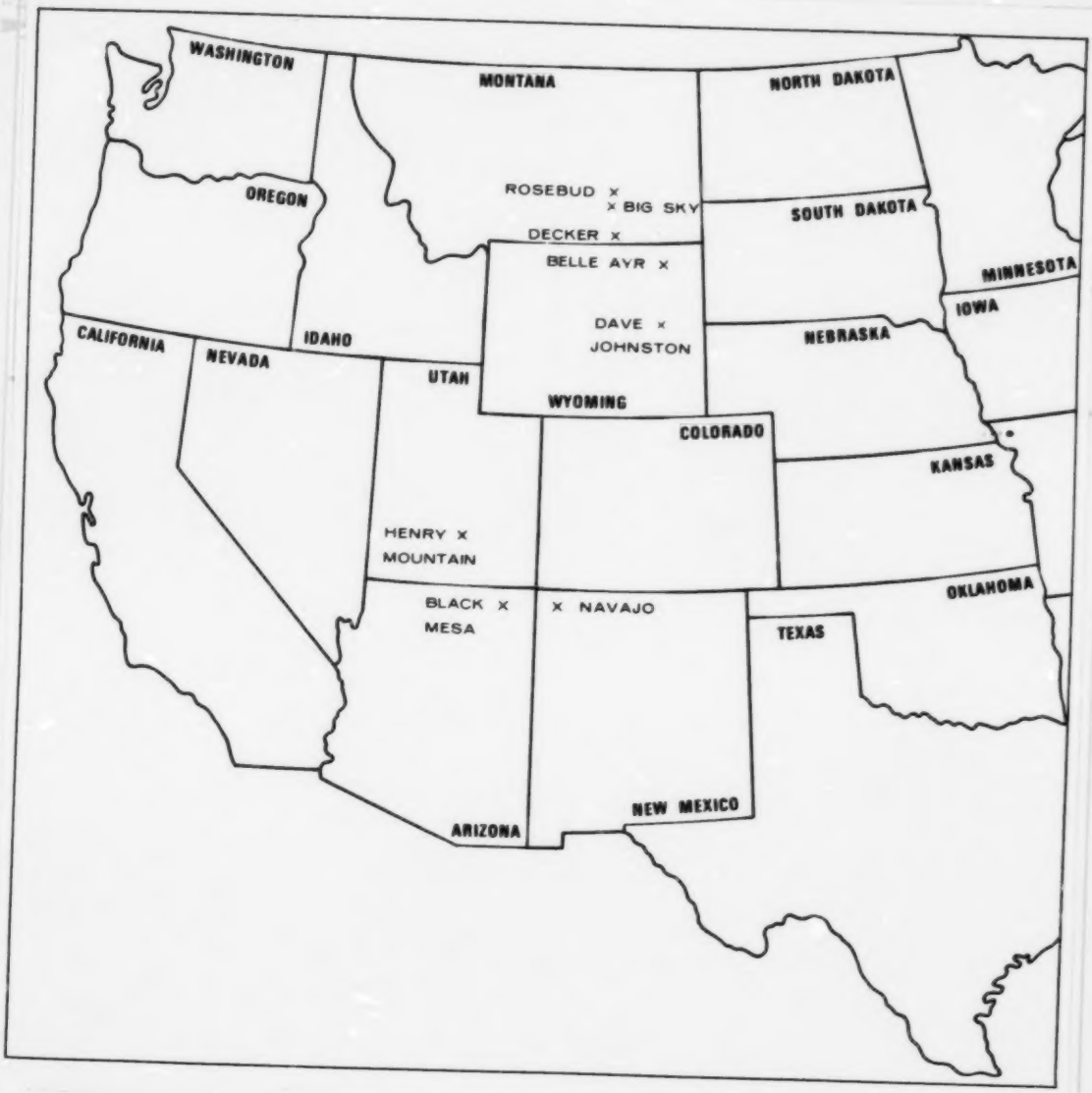

Figure 1. Locations of mine sites surveyed in Phase I.

These photographic enlargements, along with corresponding 7½-minute or 15-minute quadrangle maps, were annotated with required flight lines and start and stop coordinates for each mine. All aircraft data were collected by the data acquisition system on board NASA/Johnson Space Center's NP-3A aircraft.

During the missions multispectral scanner data were collected at altitudes of 914, 1,828, and 3,657 meters (3,000, 6,000, and 12,000 feet) above mean terrain elevation. Also photographic coverage was obtained at altitudes of 305, 914, 1,828, and 3,657 meters (1,000, 3,000, 6,000, and 12,000 feet) using both color and color-infrared film with 60 percent forward overlap.

After the aircraft data collection was completed the film was processed by EMSL-LV and duplicate positive transparencies and prints were supplied to NSTL for use in their analysis. The multispectral data were reduced and processed at NSTL.

DATA REDUCTION AND PROCESSING PROCEDURES

Reduction and processing of the aircraft MSS data were accomplished through task-designed software modules on the Data Analysis System that are linked in such a manner that output from one module serves as input to another. Each module can be composed of several software programs that accomplish one major task. Figure 2 illustrates a simplified flow diagram that outlines the reduction and processing of data from an aircraft multispectral scanner.

Immediately following data acquisition, the MSS data were decommutated and reformatted. The decommutation/reformatting process converts the PCM (Pulse Code Modulated) format of the original aircraft data into a digital format compatible with the DAS. The digital tape that is produced by the decommutation/reformatting procedure is checked for data anomalies such as data drop-outs, sun angle manifestations, recording problems, etc. Most anomalies can be corrected by the application of software programs in the preprocessing and transformation block shown in Figure 2. A data quality check can be performed by analyzing a hard copy product that is the result of intermediate processing, or by viewing the data on the interactive display system.

After the data decommutation operation was completed, a supervised approach to pattern recognition was employed by the analyst and was initiated in the Pattern Recognition Modules. This approach requires that the analyst know something about the scene because he is responsible for "training" the computer to recognize the various land cover categories that are of interest. This was accomplished by using the Interactive Processing System (Figure 3) to outline areas of known physical characteristics and then computing statistics (means, variance, correlation matrices, etc.) for each training sample and grouping the samples into land cover classes.

The Pattern Recognition Modules were written to accommodate a maximum of 4 channels of digital data. It was therefore necessary to run the Channel

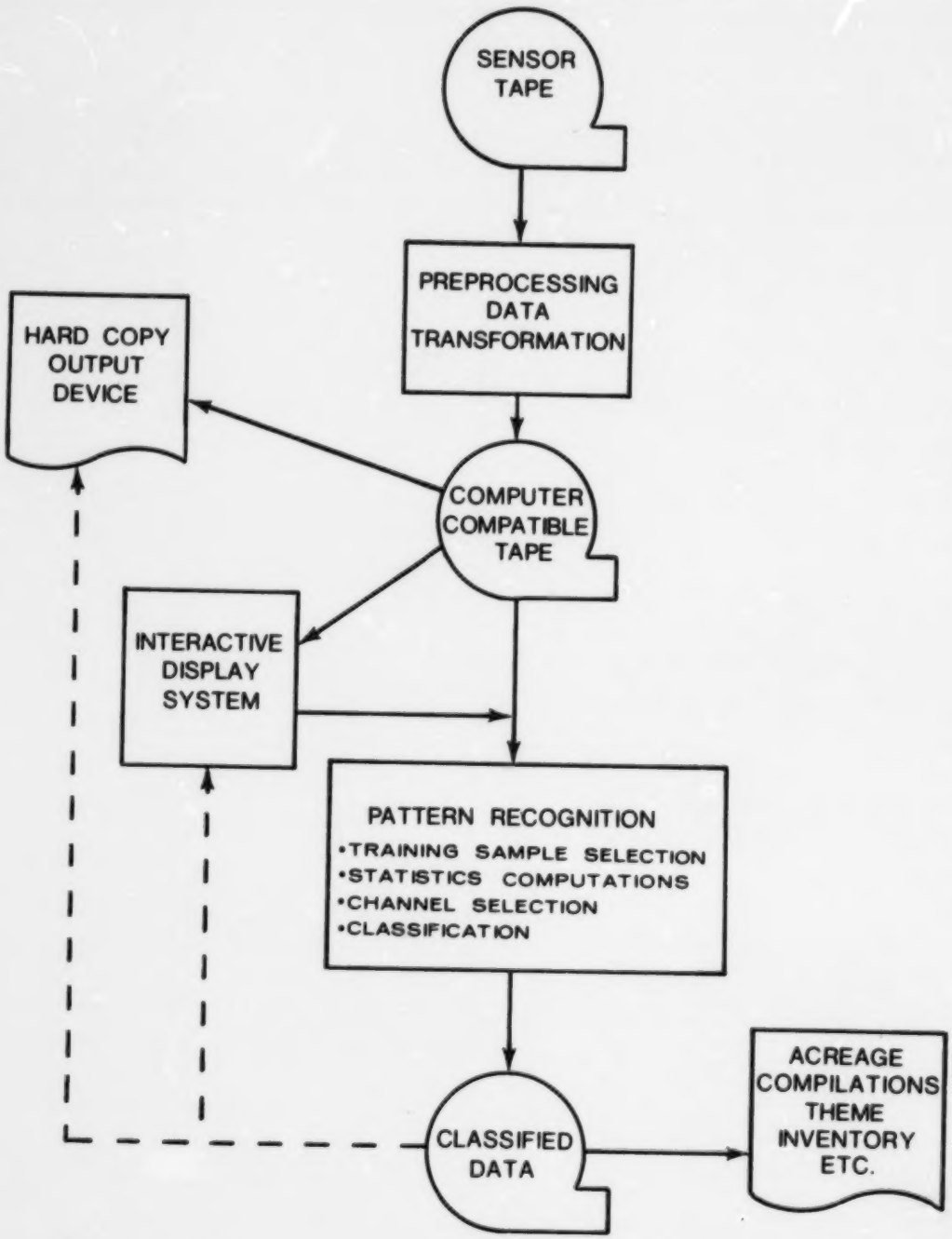

Figure 2. Multispectral scanner data reduction and processing flow (simplified).

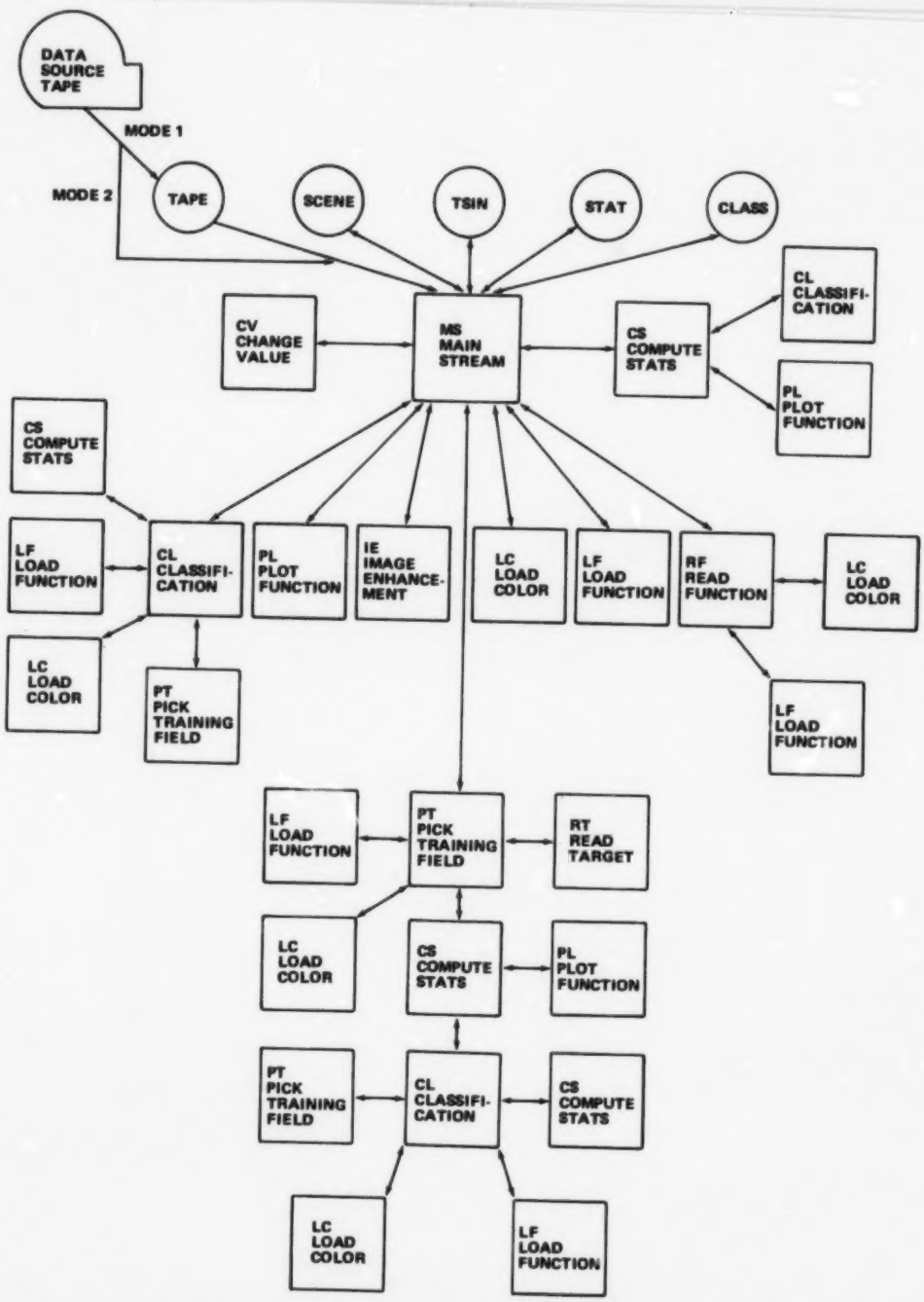

Figure 3. Graphical outline of the Comtal Varian Interactive Processing System (CVIPS) program.

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Selection Program to determine the 4 channels for use in classifying each data set. Once the 4 channels had been determined the analyst proceeded as outlined in Figure 2.

CONVENTIONAL ANALYSIS PROCEDURES

Included also in Phase I was the analysis of coal strip mines using aerial photography. The photo analysis of the mines was performed using a zoom-stereoscope, a light table, and the classification hierarchy presented in Table 1. First, appropriate stereo-pairs of each coal strip mine were located within the roll of duplicate positive transparencies. Next, transparent overlay material was placed over one frame of imagery and the features of interest were outlined and annotated on this overlay. When the frame of imagery was completely interpreted, the overlay was forwarded to the EPA cartographic laboratory for scribing (scribing produced a "clean" product, e.g., lines are of equal width, numbers are the same size, etc.). These interpreted sets of photography were later used to evaluate the accuracy of the multispectral analysis.

TABLE 1. LAND COVER CLASSIFICATION HIERARCHY FOR COAL STRIP MINE MONITORING

00 - Active Mine Features

- 01 - Advance cut
- 02 - Topsoil stockpile including embankment
- 03 - Stripping bench, highwall, open cut, pit, and related features
- 04 - Exposed coal seam
- 05 - Raw spoil bank and/or sideslope
- 06 - Coal storage pile
- 07 - Recontoured spoil
- 08 - Haul road including cuts, fills, turnouts, etc.
- 09 - Misc. disturbed areas within active mine complex

10 - Barren Land

- 14 - Shorelines, river banks
- 15 - Badlands (barren silts and clays, related metamorphic rocks)
- 18 - Man-made barrens

20 - Water Resources

- 21 - Settling ponds
- 22 - Pit ponds
- 23 - Undifferentiated ponds, lakes, and reservoirs
- 24 - Water courses, including canals

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TABLE 1. (Continued)

30 - Natural Vegetation

31 - Herbaceous types
32 - Shrub/scrub types
33 - Savanna-like types
34 - Forest and woodland types

40 - Cultural Vegetation (plantations and seedings)

Numerators

41 - Grass/forb seedings
42 - Tree/grass or tree/scrub plantations
45 - Seeding trails and test plots

Denominators

A - Vegetative cover 80 - 100
B - Vegetative cover 60 - 80
C - Vegetative cover 30 - 60
D - Vegetative cover 5 - 30
E - New seeding, vegetative cover less than 5

1 - Production level better than native level
2 - Production level about equal with native level
3 - Production level less than native level

50 - Agricultural Production

51 - Field crops
56 - Fallow land

60 - Urban/Industrial

61 - Residential
62 - Commercial and services
63 - Industrial
64 - Industrial
65 - Transportation, communications and utilities
66 - Resource extraction

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PHASE I RESULTS

The results of Phase I analysis indicated the feasibility of using aircraft-acquired multispectral scanner data for monitoring and evaluating coal strip mine rehabilitation activities. It was determined that multispectral scanner data acquired by an aircraft at an altitude of approximately 3,660 meters (12,000 feet) appeared to possess sufficient spatial resolution for vegetation/land cover classifications of western coal strip mine sites and their environs. Also, adequate details of land cover features could be obtained at 3,660 meters. It was further determined that the additional details gained from low-altitude coverage would not compensate for the necessary increase in data processing.

Finally, it was concluded from a Chi-square analysis that there were no significant differences in the results of the land cover mapping achieved through computer-implemented techniques and the land cover mapping obtained from conventional photointerpretation methods for the same land-cover classes.

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SECTION 5

PHASE II

Phase II was begun in January of 1977 at the laboratories involved. EMSL-LV was responsible for performing a shakedown of the system for monitoring purposes. During the same time frame, NSTL personnel investigated problems specifically defined by EMSL-LV which required additional research. During Phase II, EMSL-LV addressed the development of a procedure that would maximize the data acquisition system defined and assembled at NASA/NSTL. "Turn-around-time" was of critical importance in the foundation of this procedure.

DATA ACQUISITION

The aircraft multispectral scanner and aerial camera shown in Figure 4 were used to collect data over the selected coal strip mines in late June of 1977. The airborne multispectral system is capable of collecting data at altitudes ranging from 152 meters (500 feet) to 6,096 meters (20,000 feet) above ground level. The system was designed to collect and record radiant energy data in the near ultraviolet through the thermal infrared portions of the electromagnetic spectrum (Table 2).

The aerial camera that is part of the onboard instrumentation is a 15.240 centimeter (6-inch) focal length metric mapping camera. Its primary use is as a ground-coverage documenting camera. The film/filter combinations and exposure techniques are chosen to obtain photographic imagery in the desired spectra of interest.

DATA PROCESSING

Data processing began after the scanner data had been recorded on a high density digital tape and returned to the EPA laboratory. The aircraft-acquired multispectral scanner data was converted into another format because conventional computers, such as the Varian operating system for the DAS, cannot read the data format produced by an aircraft multispectral scanner. Therefore, a special device had to be designed to convert aircraft multispectral scanner data into the format expected by conventional computers. This reformatting procedure is termed decommutation and it occurs in the high density digital tape frontend hardware. Following the decommutation operation, standard data processing techniques were applied to all other functions (Figure 2) in order to produce a classified image and appropriate statistical data.

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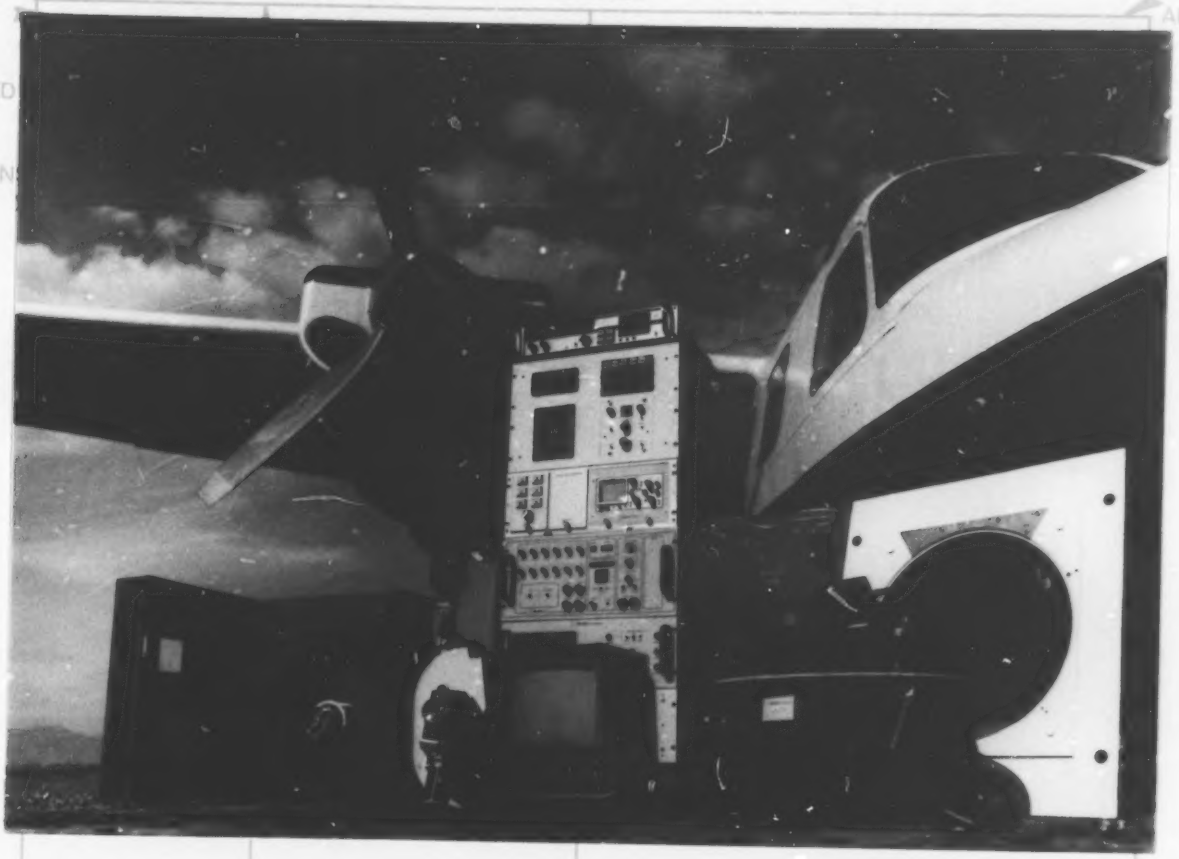

Figure 4. Daedalus 1260 multispectral scanner system and RC-8 metric mapping camera.

DATA ANALYSIS

Processing of the data sets was initiated after a photointerpretation hierarchy and a MSS data processing hierarchy were developed. In this phase it was felt that a Level I/II hierarchy would prove to be more economical and a faster means for producing results that were needed to implement monitoring-type operations over coal strip mines.

In Phase II a combination approach to pattern recognition was used. First, the raw data were classified by a sequential clustering algorithm (UNSUP) and, second, the image generated by the sequential clustering algorithm was then used to facilitate the selection of homogeneous training samples for use in other classification approaches to pattern recognition.

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TABLE 2. MSS WAVELENGTH BANDS

Channel	Wavelength Band	Color/Spectrum
1	0.38 - 0.42 μm	Near ultraviolet
2	0.42 - 0.45 μm	Blue
3	0.45 - 0.50 μm	Blue
4	0.50 - 0.55 μm	Green
5	0.55 - 0.60 μm	Green
6	0.60 - 0.65 μm	Red
7	0.65 - 0.70 μm	Red
8	0.70 - 0.79 μm	Near infrared
9	0.80 - 0.89 μm	Near infrared
10	0.92 - 1.10 μm	Near infrared
11	8.00 - 14.00 μm	Thermal infrared

Classification Program - UNSUP

The clustering program used to produce the hard copy product shown in Figure 5 uses an algorithm that groups pixels with similar statistical characteristics. The major assumption in the program is that the data exhibit some homogeneous features. Success at implementing this program was dependent upon the analyst's knowledge of the data set. An understanding of the spectral range, approximate number of classes that can be generated, the categories that may possibly cause confusion, the best channels to use for discrimination, and the number of channels with which to work were essential.

The data flow for the clustering program is straightforward. First, an initial population is established; then statistical profile tables for each class are developed. Third, the program compares the picture element with each of the established populations to determine where it best fits. Finally, additional populations are established whenever needed.

Figure 5. Contact print of the classified aircraft digital scanner data produced by the clustering algorithm UNSUP.

As stated earlier, each pixel of the digital data is compared to the existing statistical profiles to determine which population it best fits. When all the pixels had been assigned to one of the active populations or to zero population, the run terminated and the results were saved on a 9-track (800 BPI) magnetic tape. Statistics that were generated during the run and stored in the computer are dumped to the line printer device for printing. These hard copies are used in color-coding the images and grouping similar land-cover areas.

After color-coding the images, a special software program was used to convert the classified digital imagery to a format acceptable to the film recorder. The images were filmed in color and prints such as that shown in Figure 5 were then produced for use in presentation and/or reports similar to this.

PHASE II RESULTS

The aircraft-acquired MSS data assessment of the areas affected by strip mining and reclamation activities was performed in a single phase analysis through the use of the DAS. The use of the MSS Computer-compatible tapes with the DAS and other available software provided a reliable means for detecting affected areas at coal strip mines.

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The clustering program, which was the primary software classification algorithm, was capable, in most instances, of detecting and distinguishing various earth surface conditions and land cover situations (mine-related and nonmine-related) in the study area.

The results, six classification maps, generated by the clustering algorithm provided needed information for future planning and data for incorporation into the EPA data base. The data base will be an important tool in the temporal analysis of MSS data. The data reduction and processing techniques developed at EMSL-LV produced additional capabilities and provided a means of quicker assessment of coal strip mining. Also, the acreage compilation algorithm generated reliable statistical data which are essential in determining the progress of reclamation work conducted by coal mining companies.

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SECTION 6

PHASE III

In the Phase III operations, new software was acquired from NSTL and additional hardware was purchased and added to the old DAS configuration. These upgrades afforded the analyst an opportunity to develop a procedure for processing scanner data acquired over coal strip mines.

The clustering approach to pattern recognition, UNSUP, used in Phase II was not an ideal procedure. There were several problems associated with UNSUP but the two more critical problems that justified the search for a better procedure were:

- UNSUP has no memory in the form of statistical data that can be retained from one run to the next. Each set of data to be processed is treated independently. Consequently, the only manner in which the program can form classes is to start at the beginning of each tape or tape segment. Since the data are statistically different in each tape, the classes will be formed differently on each UNSUP run making it almost impossible to butt-join the results of two tapes.

- New classes are formed by the UNSUP program as it encounters statistically different materials. This results in materials being sorted into one class for a portion of the scene and then being inserted into a new class when it is formed by the program. When colors are assigned, this anomaly appears as a discontinuity in the classified data that occurs at the scan line at which the new class was formed and continues throughout the data set. This phenomenon may occur several times during a run and is beyond control of any input parameter.

SOFTWARE UPGRADE

Phase III of the Western Energy Overhead Monitoring Project was begun in June of 1978. The overall objective of this phase was to develop an update to the procedure formulated in Phase II. This updated procedure would utilize aircraft-acquired MSS data, the new software developed at NSTL, and the expanded hardware capability of the DAS. Among the software received from NSTL were three programs that served as the nucleus for the updated procedure. The first program, SEARCH, was developed as a trainer for a maximum likelihood classifier. SEARCH evaluates a six-scan-line by six-element block of 4-channel input data by the use of its covariance matrix. The statistics

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developed from a SEARCH run are stored in the Comtal Varian Interactive Processing System (CVIPS) statistics file. These statistics can be updated, merged, and used to classify a data set using the second NSTL program, the maximum likelihood classifier (MAXL4).

The NSTL version of a maximum likelihood classifier is limited to processing four channels of data; hence the acronymn MAXL4. MAXL4 classifies each vector $\underline{X}$, where $X^t = (X_1, X_2, X_3, X_4)$, as belonging to one of 63 classes or under certain conditions as "other". The mean vector, $\underline{M}$, and the covariance matrix, $\underline{C}$, are estimated from training information supplied by the statistics file from the program SEARCH.

The third program developed at NSTL provided the long-needed aircraft registration capability that would allow classified data to be input to a data base for comparative analysis. The aircraft geographical reference module was designed to be used on multispectral scanner data collected by aircraft that lacked the sophisticated instrumentation for recording altitude parameters.

This module features an option to correct the multi-channel multispectral scanner data using bilinear interpolation and an option to correct classified data using a nearest neighbor resampling method. There is also an option to choose the resampling size (not necessarily square). An important advantage to this module lies in the fact that the results are adaptable to fit a georeferenced data base system.

Such a data base for storing LANDSAT information is available and a similar one for storing aircraft-acquired data is being developed and tested by NSTL. When delivered it will greatly enhance the low and medium altitude monitoring capabilities at EMSL-LV, making temporal analysis and continual data updating possible. This will facilitate the progressive monitoring of land cover changes related to coal strip mining reclamation activities.

In addition to the above programs delivered by NSTL, an unsupervised clustering program called the Iterative Self-Organizing Clustering System (ISOCLS) was recently modified at EMSL-LV and put into operation. Developed at the NASA Johnson Space Center, ISOCLS was rewritten and adapted to the EMSL-LV DAS. This EPA adaptation of ISOCLS has subsequently undergone further changes to speed up the procedure and is now called the Environmental Clustering Classification System (ENCCLS). The significance of ENCCLS is that it is an extremely rapid and accurate clustering procedure. This promising program arranges all pixels into distinct clusters whose centers are represented by their respective cluster means. The program routinely computes the distances between each pixel and all the cluster centers and assigns each pixel to its nearest cluster. New cluster means are then computed and the clusters are examined to see if they should be split or combined. This entire process continues repeatedly until the cluster mean values cease to change significantly from one iteration to the next. The resulting clusters represent the categories derived from the MSS data.

HARDWARE UPGRADE

The DAS, as defined and originally assembled by NSTL, became obsolete because of increased requirements for automatic data processing. As configured by NSTL (Figure 6) the DAS had 65K of memory, 2 tape drives, a 47 x 10 word disk file, a line printer, a STATOS 33 printer/plotter, 3 interactive terminals and a PCM (pulse-code-modulated) subsystem.

In its updated configuration (Figure 7) the DAS has 192,000 words (16 bit) core memory, 235 megaword disk storage, 5 magnetic tape drives and is capable of supporting background runs and foreground activities simultaneously. The increase in memory improves processing efficiency by 80 percent and the additional tape drives support background and foreground processing. The additional disk space supports data base applications and multiple interactive users.

PHASE III RESULTS

The Phase III updated procedure provides a more flexible and accurate means of processing aircraft-acquired multispectral scanner data than the earlier multi-channel clustering program, UNSUP. This clustering program lacked the capability to input statistics, either initially or following a run that had less than 90 percent of the data classified. However, the analyst had the option to change input parameters to the program to improve the classification. This action did not always solve the problem and in some cases produced less meaningful results than the initial run. In essence, UNSUP required too many iterations to produce comparable results with first or second run results from the maximum likelihood classifier.

The program SEARCH that was intended to replace UNSUP was a faster method of clustering but it did not produce a classification tape that could be used to produce hard copies of the image for use in reports and presentations. Because of its speed in clustering and storing the data in the 8100 STAT (statistics) file this disadvantage became only an inconvenience to the analyst who had to punch the cards for the maximum likelihood classification program. By far the most difficult problem encountered while running SEARCH was knowing what values to enter for the four critical input parameters. These parameters, entered through the interactive mode, consisted of the upper and lower limits for the standard deviation, the maximum coefficient of variation, and the desired divergence for fields and classes. Regardless of the values entered for these parameters there was no way to evaluate the statistics developed by SEARCH other than processing the data through the classifier, and color-coding the image. Figure 8 is an example of such MAXL4 run and Figure 9 is the aircraft photography that was simultaneously acquired with the scanner data.

Color-coding is a little difficult because in developing statistics the program SEARCH does not have any knowledge of what the materials are other than that they are statistically similar. Individual classes produced by SEARCH are given names based on numerical order, e.g., CLS-01, CLS-02, CLS-03 ... CLS-Nn. These data, when classified, will require the analyst to assign,

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OPERATOR'S TERMINAL AND CARD READER
9-TRACK MAGNETIC TAPE DRIVES
COLOR FILM RECORDER
PLAYBACK SYSTEM AND CENTRAL COMPUTER
INTERACTIVE DISPLAY SYSTEM

Figure 6. Data analysis system as defined and assembled at NASA/NSTL.

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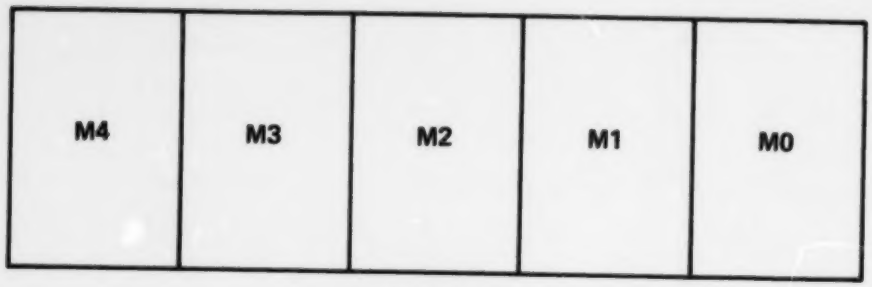

TAPE DRIVES

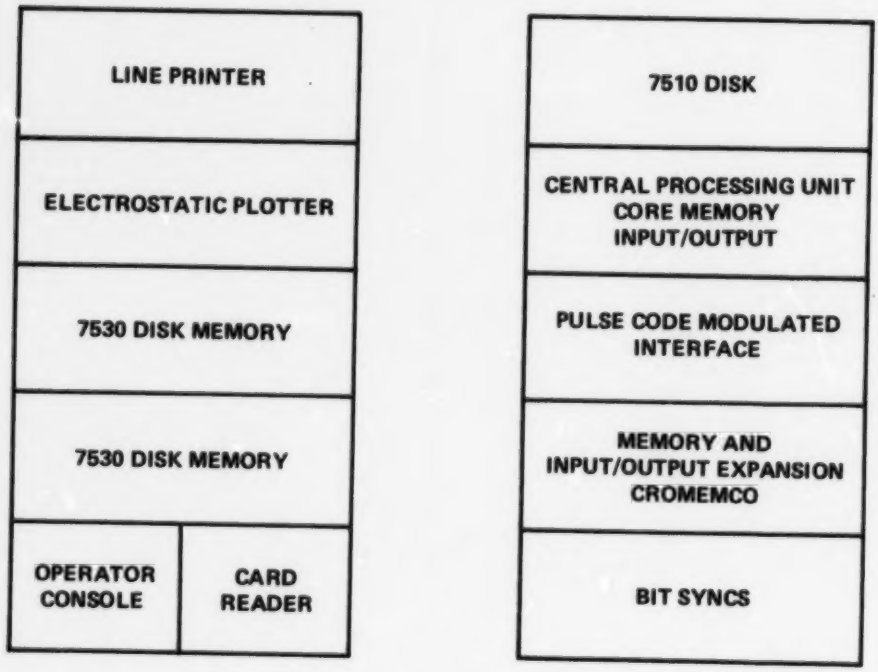

Figure 7. Updated processing hardware configuration of the EPA data analysis system.

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Figure 8. Decker strip mine classified using MAXL4.

on an individual class basis, an identification/location (ICLOC) color that will, when used in conjunction with ancillary data, locate and identify all the particular classes of material.

Various versions of the maximum likelihood classifier used in these updated procedures have been evaluated many times over the past ten years by research groups and the remote sensing community and each has proven to be a very reliable algorithm. We concur with these findings and add that it is superior to the UNSUP clustering program.

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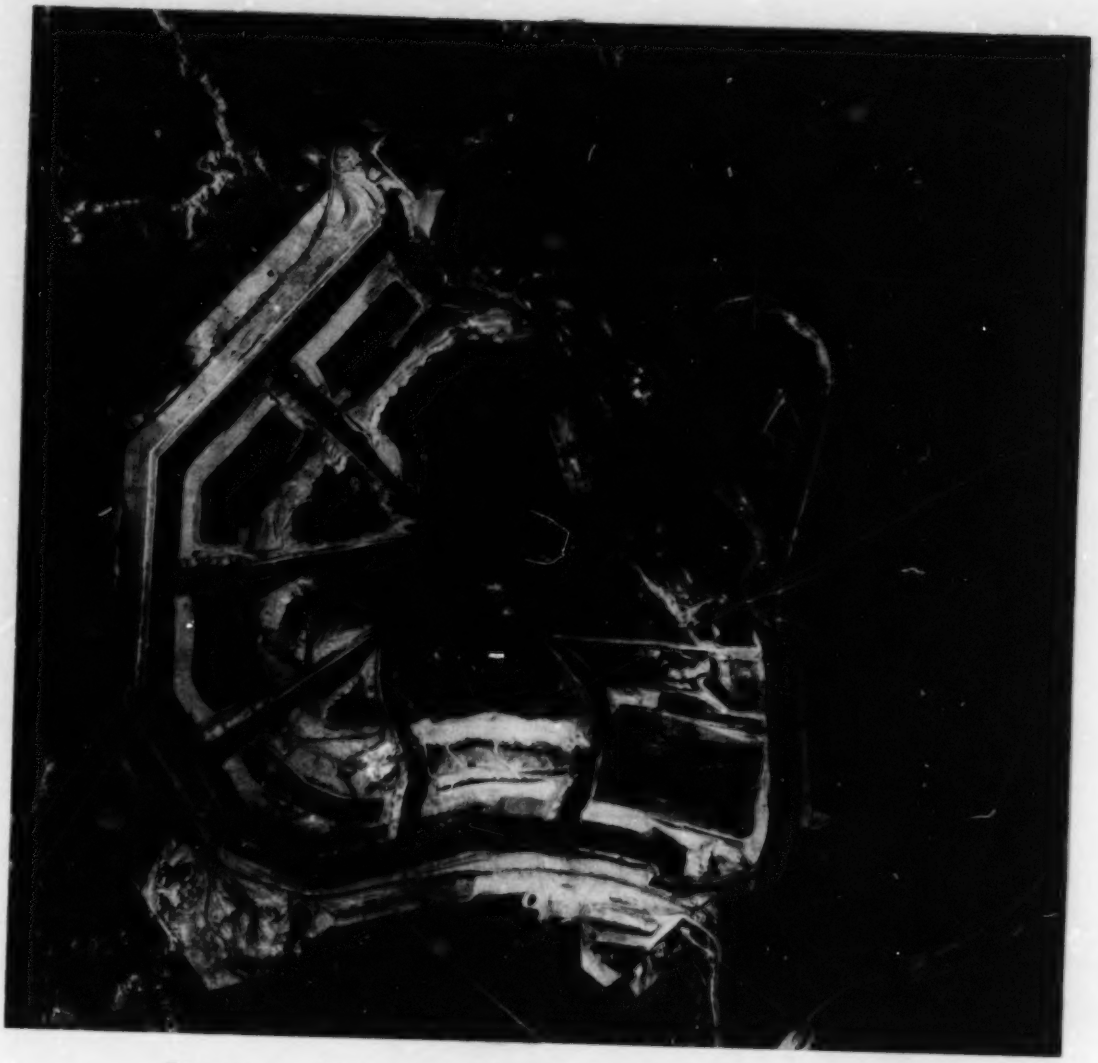
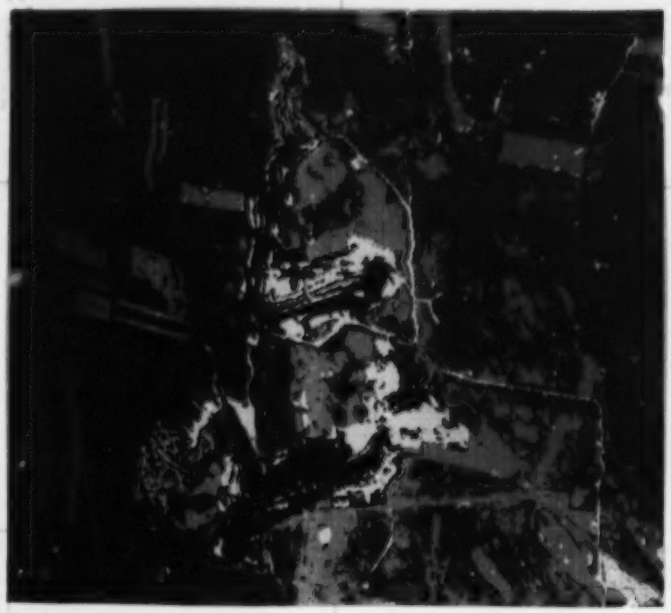


Figure 9. Aircraft photograph of Decker strip mine.

The aircraft geographic referencing program performed beyond expectations (Figure 10). With this capability we will be able to enter detailed analytical results into the EPA data base for future reference. The medium-altitude aircraft-acquired multispectal scanner data, LANDSAT data, and other digital input to the data base will certainly enhance and extend the capabilities of this laboratory.

A newly developed program that, at the time of this study, performed well is ENCCLS. The obvious advantage in using ENCCLS is the elimination of the time-consuming tasks of selecting training samples and generating training sample statistics required in the MAXL4 procedure. ENCCLS uses no training



Unregistered Data

Geo-referenced Data

Figure 10. Unregistered scanner data versus geo-referenced scanner data.

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fields, requires very little analyst interactive time, and produces classification results comparable to, or better than, the MAXL4 results. The ENCCLS program requires further investigation to evaluate its capability for reducing the analyst interactive processing time on future projects. Figure 11 shows the results of an ENCCLS run.

Figure 11. Center strip mine classified using ENCCLS.

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The recent hardware expansion extended the analysis capabilities of the DAS. The extra memory, tape drives and disk space made it possible to perform interactive analysis and run background jobs simultaneously. This capability allows the analyst the opportunity to use his interactive time more efficiently and discriminately. Where once the analyst had to decide whether a batch job or interactive analysis was more important, he may now implement both jobs.

COST ESTIMATE

A key factor to be considered in evaluating the feasibility of an overhead monitoring project, such as monitoring coal strip mining reclamation, is the cost involved. This cost is related to certain activities such as acquiring overhead aircraft data, processing and analyzing the data, and compiling the results of the analysis in a report. In Table 2 a projected cost estimate for the initial baseline monitoring of one hundred surface mines in the western United States has been put together to provide an appraisal of the cost for undertaking an extensive surface mine monitoring project.

The total man hours required for such a project is estimated to be in excess of 3,000 hours with approximately 1,800 hours allotted for analysis and documentation and the remaining 1,200 hours going to support tasks. It should be noted that the data acquisition cost will vary depending on the regional location of the mines and weather conditions at the time of overflight. For example, adverse weather conditions interfere with aerial data collection which increases collection costs. Also, mines located in the eastern United States would add to the acquisition costs because of the travel distances involved for the EMSL-LV leased aircraft based in Las Vegas.

The cost figures in Table 3 are based on the current system configuration and capabilities at EMSL-LV.

TABLE 3. COST ESTIMATE FOR THE OVERHEAD MONITORING OF ONE HUNDRED WESTERN SURFACE MINES

Item	Cost (Dollars)
Labor	39,000
Data acquisition (aircraft platform)	25,000
Computer processing	230,000
Materials	7,400
Miscellaneous	1,200
Total	302,600

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Anderson, J. E., and C. E. Tanner. Remote Monitoring of Coal Strip Mine Rehabilitation. EPA-600/7-7B-140, July 1978. EPA, Environmental Monitoring Systems Laboratory, P. O. Box 15027, Las Vegas, Nevada.

Discusses the accomplishments of the Western Energy Phase I operations. The results of manual photo-interpretation and automated data analysis are compared. Included are the results of a feasibility study to use Landsat data as a regional planning tool for pre-mining environmental impact evaluation.

Tanner, C. E. Computer Processing of Multispectral Scanner Data Over Coal Strip Mines. EPA-600/7-79-080, March 1979. EPA, Environmental Monitoring Systems Laboratory, P. O. Box 15027, Las Vegas, Nevada 89114.

Discusses the results of the Western Energy Phase II operations conducted by the Environmental Monitoring Systems Laboratory, Las Vegas. The report outlines the techniques developed and employed to obtain the classification results on a number of western coal strip mines.

_____. Overhead Multispectral Scanner Monitoring of Western Energy Coal Strip Mines. EPA, Environmental Monitoring Systems Laboratory, P. O. Box 15027, Las Vegas, Nevada 89114 (in publication).

Presents the techniques and detailed procedures developed at EPA's Environmental Monitoring Systems Laboratory, Las Vegas, for processing aircraft multispectral scanner data using an interactive computer system.

_____. Updated Overhead Multispectral Scanner Monitoring of Western Energy Coal Strip Mines. EPA, Environmental Monitoring Systems Laboratory, P. O. Box 15027, Las Vegas, Nevada 89114 (in publication).

Presents the updated data processing procedure developed during Phase III operations of the Western Energy Project and describes the upgraded capabilities of the EPA Data Analysis System.

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